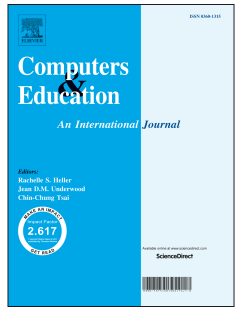
Accepted Manuscript



A review of the types of mobile activities in mobile inquiry-based learning

Ángel Suárez, Marcus Specht, Fleur Prinsen, Marco Kalz, Stefaan Ternier

PII: S0360-1315(17)30239-7

DOI: 10.1016/j.compedu.2017.11.004

Reference: CAE 3260

To appear in: *Computers & Education*

Received Date: 23 March 2017

Revised Date: 6 November 2017

Accepted Date: 11 November 2017

Please cite this article as: Suárez Á., Specht M., Prinsen F., Kalz M. & Ternier S., A review of the types of mobile activities in mobile inquiry-based learning, *Computers & Education* (2017), doi: 10.1016/j.compedu.2017.11.004.

A review of the types of mobile activities in mobile inquiry-based learning

Ángel Suárez (Corresponding author) [a], Marcus Specht [a], Fleur Prinsen [b], Marco Kalz [a], Stefaan Ternier [a]

Affiliation address
[a] Welten Institute,
Open University of the Netherlands,
Valkenburgerweg 177,
6419AT Heerlen,
The Netherlands

[b] Rotterdam University of Applied Sciences,
G.J. de Jonghweg 4 – 6
3015 GG Rotterdam,
The Netherlands

Emails
angel.suarez@ou.nl
marcus.specht@ou.nl
fleur.prinsen@ou.nl
marco.kalz@ou.nl
stefaan.ternier@ou.nl

Telephone
+3145 576 26 24

Fax
+3145 576 28 00

Present address
Open Universiteit
P.O. Box 2960
6401 DL Heerlen
The Netherlands

A review of the types of mobile activities in mobile inquiry-based learning

Abstract

Inquiry-based Learning is increasingly suggested as an efficient approach for fostering learners' curiosity and motivation. It helps learners to develop their ability to work on complex and unpredictable environments making them more critical thinkers and agentic learners. Although, mobile technology is a suitable support for this learning process, there is a lack of practical strategies for educational practitioners to enact the right balance between enabling agency and supporting the students through the mobile technology. Thus, we conducted a literature review that analyzed 62 studies on mobile inquiry-based learning. The analysis focused on the level of agency supported by mobile technology. This review study provided two main results. The first result is a two-layer classification –with five types and twelve subtypes– of the most common mobile activities used in inquiry-based learning. The types and subtypes are: 1) Direct instruction formed by 1a) location guidance, 1b) procedural guidance and 1c) metacognitive guidance, 2) Access to content formed by 2a) fixed and 2b) dynamic content, 3) Data collection that consists of 3a) cooperative and 3b) collaborative data collection, 4) Peer-to-peer communication formed by 4a) asynchronous and 4b) synchronous social communications and 5) Contextual support that includes 5a) augmented experience, 5b) immersive experience and 5c) adaptive feedback. The second result consists of an analytical framework –based on six dimensions– to assess the level of agency supported by the different types of mobile activities. The learners' agency dimensions are: 1) Goals, 2) Content, 3) Actions, 4) Strategies, 5) Reflection and 6) Monitoring. Finally, the review presents insights on how this analytical framework can be used by educational practitioners to identify mobile activities that effectively balance learners' agency with mobile technology.

1. Introduction

The term inquiry-based learning (IBL) has been defined in multiple ways in the literature. Originally, it referred to a continuous exploration of a topic of students' interest, in which learners engage in social interactions to generate shared understanding (Piaget, 1959; Pierce, 1955; Vygotsky, 1978). De Jong & van Joolingen (1998) defined it as an educational strategy based on discovering knowledge that fosters active participation and learners' responsibility. Pedaste & Sarapuu (2006) referred to inquiry-based learning as an approach in which learners solve problems by using their inquiry skills. Recently, inquiry-based learning has been increasingly suggested as an efficient approach for fostering students' curiosity and motivation by linking science teaching in schools with informal learning and phenomena in everyday life (Specht, Bedek, Duval, & Held, 2012). Such strategy can help students to develop their ability to work on unpredictable and complex environments, especially in the current, ever-changing, technology driven, society. In this context, reports like the one from UNESCO (West & Vosloo, 2013) has shown that mobile technology provides opportunities for learners to engage in a broader range of informal learning activities, especially to make learners responsible for executing learning actions. Mobile technology provides opportunities for more personalized and autonomous seamless experiences across learning contexts (Thüs et al., 2012), in which learners have freedom and power to make proactive decisions. Sharples, Taylor, Vavoula (2007) suggested that learners' agency lies in a socio-cultural synergy between all the individuals willing to advance knowing, instead of relying on the individual learner. The associated shift in the locus of control over learning (Chen, Tan, Looi, Zhang, & Seow, 2008; Sharples et al., 2005) may be facilitated by seamless learning designs that distribute agency, to make learners more self-directed.

However, increasing learners' agency and offering less support can lead to less desirable learning outcomes (Sawyer, 2005) or to learners struggling to select, organize and integrate relevant information (Kirschner, Sweller, & Clark, 2006; Mayer, 2004). That is why the scaffolding concept, used by Bruner & Sherwood (1976) as the form and quality of the effective intervention by a 'learned' person in the learning of another person, becomes essential. The division of activities between teachers and students, the required level of teachers' involvement, and the importance of students' autonomy and agency in their own learning remain important concerns to achieve efficient inquiry-based learning processes (Brown & Campione, 1994; Drexler, 2010; Kirschner, Sweller, & Clark, 2006; Klahr & Nigam, 2004; Lumpe & Oliver, 1991; Mayer, 2004; Sha et al., 2012; Song, Wong, & Looi, 2012). The issue of learners' agency in mobile inquiry-based learning has been superficially addressed in Nouri, Cerratto-Pargman, Rossitto, & Ramberg (2014). The study, that compared two inquiry-based teaching approaches with and without mobile technology, put the focus on the *different actions that were supported* with mobile technology and how those actions had an effect on the degree of learners' agency and control. This review deepens on this analysis of the actions supported with mobile technology in inquiry-based learning and how learners' agency is affected. In the remainder of this manuscript, these actions supported with mobile technology will be called mobile activities. Thus, the objective is to provide more guidance for practitioners to enable an efficient balance of learners' agency and scaffolding using mobile technology for inquiry-based learning.

This review focuses on how mobile activities in inquiry-based learning enable the distribution of agency and the balance of student support. To this end, this review is structured as follows: Section 2 underpins the theoretical background upon which this review builds: self-directed learning and agency in mobile learning and seamless inquiry support. Section 3 presents the classification framework derived, used to analyze the studies. Section 4 summarizes the outline of the methodology used. Section 5 presents the results based on the classification framework. Section 6 elaborates on the results achieved and discusses its possible implications. Last, section 7 provides the conclusion of this review with the limitations of this study and the outline for further research on the field of mobile inquiry-based learning.

2. Theoretical Background

A considerable amount of review studies has been published lately on inquiry-based learning, mainly focusing on the effect of the inquiry approaches on learning outcomes and guidance. A recent literature study (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011) investigated the effects of guidance in discovery learning approaches comparing unassisted discovery learning versus explicit instruction and enhanced discovery learning versus explicit and unassisted. The comparison showed that unassisted IBL did not benefit learners, while scaffolding and worked-out examples did. These results were aligned with the meta-analysis (Furtak, Seidel, Iverson, & Briggs, 2012) about experimental and quasi-experimental inquiry-based learning studies, in which it was suggested that teacher-led inquiry lessons had a larger effect on students' learning than those that were student-led. Another analysis of the literature focused on the structure and phases of the inquiry (Pedaste et al., 2015). The results presented a synthesized framework that proposed a general structure for inquiry-based learning in order to ensure effective implementation of inquiry-based learning processes. More recently, a meta-analysis (Lazonder & Harmsen, 2016) has also confirmed that guidance is pivotal to successful inquiry-based learning. In this study authors compared the effectiveness of different types of guidance for a different range of age. The results demonstrated that learners who received some kind of guidance improved learning outcomes, but the specificity of the guidance received and the age of the learners did not affect the results.

Other more recent reviews have been focusing on inquiry-based learning supported with mobile technology. Zydney & Warner (2016) identified typical designs with mobile apps (technology-based scaffolding, location-aware functionality and digital knowledge sharing and construction) but also suggested some recommendations for better alignment of the learning theories and the measured outcomes. This review determined that basic scientific knowledge or conceptual understanding were the main outcomes measured in the studies, and more effort from researchers was needed to assess high-level cognitive outcomes like cognitive load or problem solving. Another analysis on the effects of mobile technology on inquiry-based learning (Sung, Chang, & Liu, 2016) focused on the shortcomings linked to the duration of interventions, the methods of measurement of higher-level skills, and also on the weak orchestrations of mobile activities in generic learning activities. This supports the idea that student's activity alone is not enough to explain learning outcomes; scaffolding is often distributed in the learning environment, across the curriculum materials or educational software, the teachers or facilitators, and the learners themselves (Puntambekar & Kolodner, 2005). Despite the results of earlier reviews on (mobile) inquiry-based learning, none have yet analyzed the relation and impact of using mobile technology on learners' agency.

2.1. Designing seamless inquiry support

Sharples in (Wong, Milrad, & Specht, 2015) defined Seamless Learning as a continuous flow of meaning-making despite the changes in the physical and the social context. In the literature, different learner-centered approaches can be identified: for instance, contextual learning theories originating from distributed cognition and contextual immersion, the socio-cultural perspectives that stresses the importance of a systemic approach, constructivist approaches that highlight the importance of learner activity, and furthermore, for designing optimal learning experiences the idea of self-directed learning and scaffolding are discussed (Koole, 2009; Sharples, Taylor, & Vavoula, 2010).

In the field of inquiry-based learning, the integration of mobile technology enables new forms of guidance (Land et al., 2011), interactivity or immersion in technology-supported inquiries. Koole (2009) defines aspects of the device, aspects of the learner and social aspects as part of the complex interaction of mobile learning support. Based on her framework balanced and effective learning experiences can be designed by these aspects. In a similar approach, Luckin (2010) defines a framework in which learning takes place in an Ecology of Resources (EoR). She uses the concept of filters to select relevant resources for supporting learning in the current context. Considering the special case of mobile language learning, Kukulska-Hulme (2009) points out that the focus of attention is actually on the *pedagogical interactions* and less on the nature of the technology being mobile or fixed. Taking learning outdoor benefits learning, as it facilitates an active interaction process between the learners and their environment (Fahraeus, 2004; Wilde, Harris, Rogers, & Randell, 2003).

The context-bound nature of learning is also emphasized in socio-cultural approaches. As Säljö (2010) argues, our knowledge is built through our application of external tools (intellectual, physical, or both), which we integrate into the flow of our activities. Learning is mediated by conceptual and physical artifacts and by other people, in an interacting system of elements. Sharples, Taylor, & Vavoula (2010) postulated that knowledge is embodied in the elements of a distributed system and in the interactions between those elements. The capabilities of mobile technology enable learners to hold conversations across multiples contexts and to generate synergies to co-create knowledge.

De Jong, Specht, & Koper (2008) provided a reference model for mobile social software, engagement and immersion. In their framework they analyzed the participating stakeholders, embeddedness into the context, underlying pedagogical paradigms and the data flow of different mobile social applications. Park (2011) proposed a framework to classify the pedagogical affordances of mobile designs based on the attributes of mobile devices; the mobility hierarchy defines four levels to cluster mobile devices and their pedagogical affordances as productivity, flexible physical access, capturing and integrating data, and communication and collaboration support.

Taken together, all these learner-centric approaches supported with mobile technology offer suitable learning activities, at the right time and place (Peng, 2009). These different types of mobile activities – that will be used later for the classification framework– provide ubiquitous capabilities for learners to receive specific instruction, guidance and content when they need it (Kukulska-Hulme, 2009; Luckin, 2010). Learners can socially interact and co-create knowledge among distributed participants in a community (Koole, 2009; Säljö, 2010; Sharples et al., 2010). They can also back up their investigations digitalizing evidences for later analysis and reflection (Tabuenca, Kalz, Drachsler, & Specht, 2015; Verpoorten, 2012). Mobile activities can also bridge learners and their environment for supporting more augmented experiences (Fahraeus, 2004; De Jong et al., 2008; Wilde et al., 2003). These properties were also mentioned in (Zydney & Warner, 2016) as part of the typical designs featured with mobile apps in inquiry-based learning. However, *do these properties really lead to effective seamless learning?* This question, that has been raised by Vogel, Kennedy, & Kwok (2009) and shared by Wong, Milrad, & Specht (2015) in their book, suggesting that just using mobile technology for (inquiry) learning does not necessarily lead to meaningful seamless learning processes. Eventually, this also requires learners to be agents of their own learning in a way that they control their behavior and cognition (Wong, Milrad and Specht, 2015). So, the key question is to what extend those learner-centric approaches supported with mobile technology enable learners to take the responsibility on their learning process (learners' agency).

2.2. Learners' agency

During the last decades autonomy and agency have been central to education, and they have been used indistinctly to refer to the ability or capacity to take control of one's own learning (Benson, 2007; Holec, 1979; Holec, 1981) or to refer to the capacity to act with initiative (or self-regulation) and effect in one's own learning (Fay, 1996; Lantolf & Pavlenko, 2001). Some authors (Hunter & Cooke, 2007) have claimed that the initiative aspect is the differentiator between autonomy and agency. They argued that learners' agency comprises the initiative of the learner, whereas learners can act autonomously even when they have received specific instructions before. All in all, learners' agency assumes learners to be responsible for the purpose of their learning, the content, the rhythm and the strategies they used as well as for monitoring the progress and assessing its outcomes (Little, 2007). Controlling the process of one's own learning is strongly linked to the concept of self-regulated learning. In its definition (Zimmerman, 1990), learners are characterized by having the control over their metacognition, motivation and behavior, which help them to achieve desired learning outcomes. This definition was extended in the socio cognitive theory of (Bandura, 2001; Zimmerman & Schunk, 2001), in which self-regulated learners should be also able to define their own motivational and metacognitive strategies, manage their own learning situations and choose the right amount of instruction needed. Moreover, as part of the social cognitive theory, Bandura (2001) defined agency as the capability of humans to set a goal and act on these choices. Additionally, he provided four main features that characterized human's agency: a) intentionality, that refers to the power to originate actions. b) forethought, that suggests that an agent should anticipate his/her goals and take the appropriate action to achieve them, c) self-reactiveness, that refers to the power to not only plan and think ahead, but also to motivate and self-regulate as well and d) self-reflectiveness, as the capability to subjectively judge their own performance and assimilate also external feedback.

Several critiques in the literature associated to the lack of support and guidance in discovery learning processes (Kirschner et al., 2006; Mayer, 2004) claimed that enabling too much freedom can generate less desirable learning outcomes and make learners struggling to select, organize and integrate relevant information. Such critiques leverage the need to achieve more understanding of the role of mobile technology supporting learners' agency. Although there has been some preliminary attempts to discuss this issue in the context of inquiry-based learning (Nouri et al., 2014), this manuscript aims at providing practical strategies to scrutinize how learners' agency and scaffolding can be better identified when using mobile technology. Taken together, the agency definitions described in this section will be used in the next section to define the dimensions that will characterize learners' agency.

3. Analytical framework

To ensure the identification of the opportunities for exercising learning agency in inquiry-based learning supported with mobile technology, this review looks at the link between learners' agency and the state-of-the-art of mobile device and mobile applications found in literature. In order to conduct this research, this review proposes a review framework which is based on the definitions of learners' agency.

Starting from Benson's (2007) and Holec's (1979, 1981) ideas of learners' agency, we developed an analytical framework to analyze learners' agency while using mobile technology in inquiry-based learning. The framework includes six dimensions and it is based on the following four definitions of agency proposed by Bandura (2001): goals, actions (extracted from intentionality feature), strategies (extracted from the forethought feature) and reflection (extracted from the self-reflectiveness and the self-reactiveness features). This framework was complemented with Little's (2007) definition that includes control, and with Zimmerman's (1990) definition that incorporates monitor control (extracted from the self-regulation theory). The six dimensions of the analytical framework are:

- **Goals**: Does the learner have any opportunity to set up his/her own learning goals?
- **Action**: Does the learner have any opportunity to decide what to do?
- **Strategy**: Does the learner have any responsibility on how to do it?
- **Reflection**: Does the learner have any opportunity to reflect upon the strategies used to execute the process?
- **Content**: Does the learner have any opportunity to decide which information he/she wants to use?
- **Monitoring**: Does the learner have any opportunity to monitor his/her progress?

4. Method

4.1. Selection

Following the structure proposed by the PRISMA statement, as a guideline for undertaking systematic reviews (Moher, Liberati, Tetzlaff, & Altman, 2009), the underlying exploration was conducted in April 2016 using the following databases: Elsevier and Web of Science were used because they contain journals that publish research combining educational and technical aspects. ACM and Springer were selected because they contain one of the largest digital libraries for conference proceedings. And finally, Taylor & Francis was used for covering subjects in education, engineering and social science.

The search for articles was done in three iterations. The first iteration was performed using the keywords included in the identification phase (see Figure 1). In this case, we examined the abstracts of the articles looking for studies describing inquiry based learning processes supported with mobile technology. This identification phase left 110 articles that were considered for further analysis. In the screening phase, 5 duplicates were removed. In the eligibility phase, we filtered out 43 articles without practical implementations of mobile inquiry-based learning, i.e. theoretical studies. Since not a lot of experimental studies were found, case studies and semi-experimental were also considered for the analysis. At the end, 62 studies were retained for an in-depth analysis.

We focused on inquiry-based learning, inquiry learning and science inquiry, because we considered these terms to be sufficient for our analysis. In addition, the review covered studies in the timeframe between the appearance of the first smartphone in 2006 until to 2016.

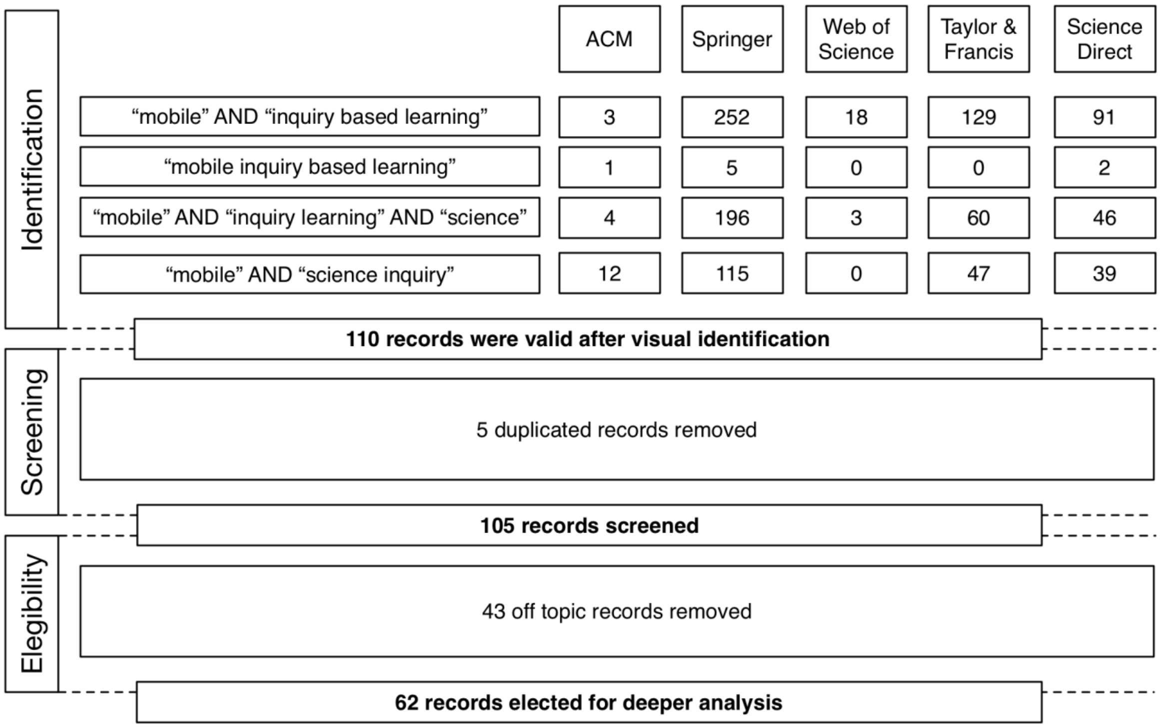


Fig. 1. Research methodology according the PRISMA framework.

4.2 Analysis

Previous review studies on inquiry-based learning (Furtak et al., 2012; Lazonder & Harmsen, 2016; Maaß & Artigue, 2013) and mobile inquiry-based learning (Sung et al., 2016; Zydney & Warner, 2016) have already addressed topics like learning outcomes, strategies for the practical uptake of IBL, effects of using mobile technology for IBL or the effects of guidance. However, the issue of learners' agency has been addressed superficially in few occasions like e.g. in Nouri et al. (2014). Thus, to deepen in the analysis of how the different types of mobile activities affect learners' agency, a three-step process analysis has been carried out.

Following a joint iterative coding approach (Bogdan & Biklen, 1998; Huberman & Miles, 2002), the first step of the analysis was to cluster all types of mobile activities found in the studies. For that, an initial classification of types of mobile activities has been created based on the ubiquitous pedagogical capabilities of mobile technology described in section 2.1. A *ubiquitous pedagogical capability* is a unique affordance that mobile technology provides to support learning. The initial types were: 1) direct instruction, 2) access to content, 3) data collection, 4) enable communication and 5) contextual support. At the end of this first step, these types were refined and became the final 12 types of mobile activities supported in inquiry-based learning (see Appendix A). The second step consisted of the development of the analytical framework presented in section 3. Out of the existing definitions of learners' agency, 6 dimensions were developed in order to understand to what extent a type of mobile activity supports or limits agency. In the last step of the analysis, the 12 types of mobile activities have been analyzed according to the 6 dimensions of learners' agency that focus on the learners' control over goals, content, actions, strategies, reflection and monitoring. To decide whether a type of mobile activity complies with a given agency dimension, we looked in the studies for evidences that explain the signs of agency. A type of mobile activity complies with an agency dimension when at least one example –explaining how this agency dimension is supported– is found in the studies. Conversely, if a type of mobile activity does not comply with an agency dimension can be due to two reasons: either for a given type of mobile activities there were no evidences in the studies that support the agency dimension, or there were signs that the agency dimension was limited in at least one of the studies.

5. Results

In this review, 62 studies were selected for further analysis. Out of the initial grouping phase, the distribution of types of mobile activities over the 5 major categories (see Appendix A) was the following: fostering teachers' direct instruction (44/62 studies – 70%), access to content (43/62 studies – 69%), supporting data collection (57/62 studies – 91%), facilitating social interaction (20/62 studies – 32%) and enabling interactions between the context and the learner (16/62 studies – 25%). In this section, examples of the different types of mobile activities are given together with the analysis of the learners' agency based on the 6 agency dimensions. Thus, two tables will be included in each sub-section; the first table contains examples of mobile activities, the number of times that they were found in the different studies and which technological affordances of the mobile devices were used. The second table contains the scores of each type of mobile activity based on the 6 agency dimensions: goal, content, action, strategy, reflection and monitoring.

5.1 Direct instruction

The most basic form of support in formal and informal learning is direct instruction. Inquiry-based learning, especially when it takes place in out-of-the-classroom settings, is based on ill-structured inquiry activities that require a lot of support and guidance from the facilitators. This type of mobile activities facilitates such support even when participants are distributed across different locations. In the reviewed studies there is a continuum of direct instruction and guidance that work on different levels (location guidance, procedures and metacognition). These 3 levels –represented in table 1– are 3 of the 12 type of mobile activities mentioned in 4.2.

Table 1. Types mobile activities supporting access to content

Direct instruction	Number of studies	Technological affordances
Location guidance	27	GPS, Radio Frequency Identification (RFID), Quick Response Codes (QR codes), Personal Digital Assistants (PDAs) & Geocaches
Procedural guidance	16	Task/process execution, question-guided tours, process or

		collaboration scripts
Metacognitive support	4	Mental model construction, carry out interpretations, scaffolding to understand scientific concepts, reducing cognitive load in data collection & interpretation processes.

Location guidance instructions (used in 27 studies; see table 1 and Appendix A) cover types of mobile activities that explicitly move learners through different locations either in sequence or different forms of exploration. Examples of this type of mobile activities are fieldtrips or museum visits that usually are combined with technological affordances like GPS, RFID, QR codes of PDAs. Considering the dimensions of the analytical framework for learners' agency, it only provides opportunities for learners to exercise their control over the strategies (see table 2). Despite the learners are instructed about what to do (control over actions) and where to go, they can still decide how to do it. Although learners move around the place to get information, in the cases presented in the literature the information was given by the teacher or designer.

The direct instruction through procedural guidance (used in 16 studies; see table 1 and Appendix A) help the learner to carry out an activity or process. It helps learners executing and automatizing step-by-step processes. For example, in (Hsiao, Chang, Lin, & Wang, 2016; Suarez, Ternier, Kalz, & Specht, 2015) learners received question-guided instruction in order to help them during the data collection process. Other examples used list items or scripts to guide specific parts of the inquiry process (Anastopoulou et al., 2012; King, 2007). Regarding the dimensions of agency, the learners do have more autonomy to use their content, however their control over actions, strategies and goals is limited by the step-by-step guidance. In this case also the type of mobile activities helps learners to monitor and reflect upon their learning. In case like in Suarez et al. (2015), learners could visualize their performance after the activity, so they could reflect on action (monitoring of cognition see Akyol & Garrison (2011)).

The last level of direct instruction is the metacognitive guidance (used in 4 studies; see table 1 and Appendix A). It guides the students on what cues to reflect upon and how to construct mental models. Some examples of type of mobile activities that support metacognitive instruct learners on how to carry out interpretations (Ahmed & Parsons, 2013). Other examples provide scaffolding on how to understand key scientific concepts like animal grouping (Looi et al., 2014; Parr, Jones, & Songer, 2004). This type of direct instruction allows learners to have more control over actions, strategies and content, because this main goal of this type of direct instruction is to reflect about their cognitive processes.

Table 2. Learner's agency dimensions for the types of mobile activities providing direct instruction

Direct instruction	**goals**	**content**	**actions**	**strategies**	**reflection**	**monitor**
Location guidance	×	×	×	✓	×	×
Procedural guidance	×	✓	×	×	✓	✓
Metacognitive support	×	✓	✓	✓	✓	×

5.2 Access to content

The ubiquitous access to information is a common practice in our daily life, in which users seek, store, organize and categorize the information whenever they need it (Pachler, Cook, & Bachmair, 2010). In the context of Inquiry-based Learning, contextually relevant information integrated with prior knowledge (Rogers & Price, 2008) becomes essential to support ongoing observations and to create new knowledge in the physical environment. To this end, the appropriation of digital literacy is key to elicit good interpretations of the content delivered or consumed through the mobile device. In the reviewed studies, we found two types of mobile activities for accessing content (fixed and dynamic).

Table 3. Types of mobile activities supporting access to content

Access to content	Number of studies	Technological affordances
Fixed content	25	Local repositories, preloaded e-libraries, preloaded mobile apps, RFID tags, QR codes, Geocaches and digital artifacts triggered with GPS and AR
Dynamic content	25	Browsing, filtering, interpreting information found on the web, remote databases, concept maps, discussion forums, KWL[1] tables, online blogging, wikis and social networks.

Table 3 shows a summary of how many times and how these type of mobile activities has been used. The fixed content type (used in 25 studies; see appendix A) refers to the type of mobile activities in which the content has been prepared before the inquiry activity starts. Although the content can be stored online, in the literature it is usually stored in the mobile device to enable also offline access. For example, through mobile functionalities like e.g. RFID tags (Chu, Hwang, Tsai, & Tseng, 2010) or QR codes (Eliasson, Knutsson, Ramberg, & Cerratto-Pargman, 2013; Nouri, Cerrato-pargman, & Zetali, 2013), learners can access relevant information for the inquiry process. Examples of activities like jigsaw (Mulholland et al., 2012), scavenger hunt games or geocaching activities (Jones, Scanlon, & Clough, 2013) integrate this type of mobile activities while keeping the inquiry nature of the activity. From the analytical framework perspective, if the content consumed has been prepared by the facilitator before the inquiry activity starts like i.e. pre-loaded e-libraries (Ahmed & Parsons, 2013) or content uploaded to a mobile app (Ternier, Klemke, Kalz, & Specht, 2012), the opportunities for learners to setup their own goals can be reduced (see table 4). This is because learners will not be able to steer the inquiry process in the direction they wish to. It has been proven that ill-structured processes require a lot of guidance (Kirschner et al., 2006; Lazonder & Harmsen, 2016), but providing guidance is not strictly the same as delivering content. Guidance can be provided on how to explore learners' objectives in an optimal way, whereas delivering specific content implies giving learners everything ready to use, which in turn, can move learners away from their own learning objectives. Thus, agency over content is also not well

[1] (What do I Know? what do I Wonder? and what did I Learn?)

supported by fixed content type of instructions. The next dimension for agency refers to the opportunities for reflection while accessing content. Providing fixed content to the learners generate less chances for learners' reflection. With fixed content the learners focus on using the information given on the inquiry process, whereas with the dynamic access learners not only need to use the information but they also need to decide how suitable is the content for the purpose of the inquiry. This does not neglect the reflective capabilities that might be enacted through fixed content, but it emphasizes the bigger opportunities for learners' reflection when using dynamic access to content.

The second subcategory is dynamic content access (used in 25 studies, see table 3 and Appendix A). It refers to the type of mobile activities in which learners actively access digital sources to browse, filter, retrieve, evaluate, and interpret content that can be valuable to advance their knowledge (Liu, 2009; Shih, 2010). Another example of dynamic access to content can be the use of remote repository of information (Huang, Lin, & Cheng, 2010; Lai, Wu, Chou, & Lai, 2010), which are not as wide as the information that can be found on internet but learners still need to browse and to filter the information. These types of mobile activities –that enable learners to manage their information (dynamic access to content)– open up the opportunities for learners to exercise their agency (see table 4 and Appendix B). First the control over the goals, it depends on the design around the use of this type of mobile activity. For instance, in Song et al. (2012), authors followed a goal-based approach in which KWL tables are essential to let the learners establish their own learning goals and plans. In this case, learners had the freedom to select their own information resources. Regarding the dimensions of content, actions, strategies and reflection, the learners have intrinsically control over all of them. The reflection dimension is covered as the learners need to developed digital literacy skills like filtering or analysis in order to find suitable information online.

Table 4. Learner's agency dimensions for the type of mobile activities providing access to content

Access to content	goals	content	actions	strategies	reflection	monitor
Fixed content	×	×	✓	✓	×	×
Dynamic content	✓	✓	✓	✓	✓	×

5.3 Data collection

Since the appearance of the first handheld devices, data collection processes have played an essential role supporting the development of complex reasoning (Parr, Jones, Songer, & Arbor, 2002) and minimizing the complexity of collecting accurate data in the field (Parr et al., 2004). Defined as the process of digitalize, persist in time and organize the data in a digital shared space, data collection processes are essential to any scientific investigation.

Table 5. Types of mobile activities supporting data collection processes

Data collection	Number of studies	Technological affordances
Cooperative	57	Capturing multimedia data, taking notes, drawing schemas, multiple choice questions to guide data

		collection and collect information for KWL[2] tables.
Collaborative	8	Collaborative concept maps and graphical data visualization of data jointly collected.

From table 5, one can see that the great majority of the reviewed studies (57/62) included the type of mobile activities involving data collection processes (see Appendix A for detailed information). Some examples of cooperative data collection are traditionally activities like taking notes (Hung et al., 2013; Hwang, Wu, et al., 2011; Liljeström, Enkenberg, & Pöllänen, 2013; Shih, 2010; Song, 2014; Tan et al., 2007; Yang & Lin, 2010) or drawing ideas, schemas or concepts (Chiang et al., 2014a, 2014b; Chung et al., 2010; Looi et al., 2014; Song, 2014; Song & Kong, 2014; Sun, Looi, Wu, & Xie, 2015). However, mobile technology also offers specific affordances like annotating data samples taken, or conceptualized mental models in order to make them shareable (Chang et al., 2012; Hung et al., 2012; Razikin et al., 2009; Sha et al., 2012; Shelley, Dasgupta, Silva, Lyons, & Moher, 2015; Song et al., 2012; Yarnall et al., 2006). From our analytical framework point of view (see table 6 and Appendix B), most of features of learners' agency are covered in the type of mobile activities involving data collection. Learners are free to decide what to capture, how to do it and after the capturing the facilitators can ask the learners to reflect and to do interpretation about it. Though, there is a difference on the opportunities for monitoring their progress between the cooperative and the collaborative data collection processes provide. Before explaining such difference, the cooperative data collection processes refer to the most common form of data collection, in which students individually capture multimedia data for later analysis or interpretation. Among the traditional techniques for data collection –taking notes, shooting videos, pictures or audios–, more specific functionalities like annotating data samples or conceptualize mental model are also widely used in inquiry-based learning. Additionally, these technological affordances have been used in specific phases of the inquiry model e.g. brainstorming or idea collection for further investigation.

Conversely, the collaborative data collection processes refer to the type of mobile activities in which students collectively associate concepts, i.e. concept maps of jointly collected graphical visualizations. Technically, the main difference with the cooperative data collection is that the data is not automatically integrated, processed and merged into a unique data instance. Cooperative data collection requires a post-analysis of the collected data, while collaborative data collection allow learners to interpret the results and react immediately to them. Examples of collaborative data collection processes are i.e. associative concept mapping (Chiang et al., 2014a, 2014b; Looi et al., 2014; Song, 2014; Song & Kong, 2014; Sun et al., 2015) or jointly generate graphical visualization of the collected data during an inquiry (Rogers & Price, 2008; Sharples et al., 2015). In this particular case, the values recorded by the students were processed and combined in real time and shown to them in the for of a graph. From the learners' agency point of view (see table 6), collaborative data collection processes enable monitoring opportunities. For instance, as stated in (Rogers, 2006), learners could reflect and analyze the gathered data through collaborative data collection processes during their outdoor discoveries while still in the woodland. Such

[2] (What do I Know? what do I Wonder? and what did I Learn?)

opportunities enable a reflection in action (collaborative data collection), rather than a reflection on action (cooperative data collection) that happens when the data collection process is over (Munby, 1989).

Table 6. Learner's agency dimensions for the type of mobile activities providing data collection

Data collection	goals	content	actions	strategies	reflection	monitor
Cooperative data collection	✓	✓	✓	✓	✓	×
Collaborative data collection	✓	✓	✓	✓	✓	✓

5.4 Peer-to-peer interactions

Sharples, Taylor, & Vavoula (2010) stated that the use of mobile technology for learning situates knowledge at the center of a distributed system, in which learners hold conversations across multiple contexts. Such distribution supports the concept of shared ownership that claims that agency lies with the community of learners, rather than with the individuals.

Table 7. Types of mobile activities providing peer-to-peer interaction

Peer-to-peer communication	Number of studies	Technological affordances
Synchronous	10	Instant messaging, chats with notifications.
Asynchronous	15	Forums, online discussion panels, online platforms without notifications and social boards.

Out of the 62 reviewed studies, 20 included mobile activities to steer communication between students or between teachers and students. Table 7 shows that these studies refer to a great extent to learners interacting socially to achieve certain learning goals. In Jones, Scanlon, & Clough (2013), a system that provides means of communication was used in four projects. The results provided different levels of learners control (see table 8) regarding the choice for inquiry and process (content and strategy), ranging from limited control over the inquiry topics and process –in a birdwatching activity– until almost full learners' control (besides the design of the caches) –in a geocaching activity–. In these examples, the communications were asynchronous. Learners were not notified about the communication, so it was difficult to follow up the communications. More examples of asynchronous communications can be enact with the use of forums (Chiang et al., 2014a, 2014b; Jones et al., 2013; Lai et al., 2010; Liljeström et al., 2013), online discussion panels (Marty et al., 2013; Wong, 2013) and comments in social boards (Anastopoulou et al., 2012; Aristeidou et al., 2015; Boticki et al., 2015; Song, 2016; Song & Kong, 2014; Wong, 2013).

The synchronous communications rely on push & pull technology to increase learners' awareness about recent contributions in the inquiry or new messages available. These communications are volatile, elusive and they occur in real time, thus features like notifications are needed to keep the flow of the conversation. Some examples of this type of mobile activity can be found in studies that used instant messaging together with notifications (Chiang et al., 2014a, 2014b, Song, 2014, 2016; Song & Kong, 2014; Suárez, Ternier, Prinsen, & Specht, 2016). Comparing synchronous and asynchronous interactions, they do not only differ on the underlying technology. Both provide opportunities to reflect, but the asynchronous communications allow learners to have more quality time for reflection. They are not urged to keep up the flow of the conversation, so they can elaborate more the message they wish to convey. This type of communication might be preferable when the goal is to achieve higher order cognitive skills (Garrison, Anderson, & Archer, 1999).

Table 8. Learner's agency dimensions for types of mobile activities providing peer-to-peer interaction support

Peer-to-peer interactions	goals	content	actions	strategies	reflection	monitor
Social asynchronous	✓	✓	✓	✓	✓	✓
Social synchronous	✓	✓	✓	✓	✓	✓

5.5 Contextual support

De Jong et al. (2008) used the term contextual filters to refer to the support that mobile technology offers to learners filtering by the context the resources that can help them on their learning. Such contextual filtering or support, allow learners to explore, discuss and construct knowledge in real world scenarios (Donovan, Bransford, & Pellegrino, 1999). It bridges the gap between the learners and the environment that surrounds them.

Table 9. Types of mobile activities providing contextual support

Contextual support	Number of studies	Technological affordances
Augmented experience	12	GPS, timer or accelerometer
Immersive experience	9	GPS, big display for immersive simulation, stargazing simulation, 3D weather simulation.
Adaptive feedback	7	intelligent systems that give hint for making further observations

Only 16 of the 62 studies included mobile activities for contextual support (see Appendix A). Table 9 shows the three subcategories (augmented experience, immersive experience and adaptive feedback). First, the augmented experiences (used in 12 studies, see table 9) prompt information to the learner when he/she steps into a specific location or when certain amount of time has passed.

Thus, the context, through this type of mobile activity, creates the learning conditions for students, but the student has the control and decides what to do or to explore (Nathan & Robinson, 2001). The majority of the designs used the GPS to model this type of activity (Boticki et al., 2015; Chiang et al., 2014a, 2014b; Dunleavy et al., 2009; Huang et al., 2010; Hwang, Chu, et al., 2011; Jong & Tsai, 2016; Kamarainen et al., 2013; Laru et al., 2012; Schaal et al., 2012; Wong, 2013) (see table 10 and Appendix B). This type of mobile activities does not offer opportunities to monitor the learning progress, because they focus on the delivery of content through the context. Therefore,

Second, the immersive experiences (used in 9 studies) refer to the type of mobile activities embedded in a digital simulation. Digital simulations are frequently used in inquiry-based learning to explain complex concepts or processes that cannot be easily reproduced in real life. Examples of this type of immersive experiences have been reported in (Chen & Lin, 2016) in which students could engage in a free-form of stargazing with simulated constellations or in (Lui, Kuhn, Acosta, Quintana, & Slotta, 2014) in which students collected data in rainforest immersive simulation. Another example is the 3D weather simulation (Hsiao et al., 2016), in which learners combine factors like temperature or pressure to learn the implications those have in the weather. All in all, these immersive experiences are characterized by having learners interacting with a digital environment that augments their learning experience. Concerning learners' agency, these types of mobile activities showed options for learners to control all the agency dimensions.

Last, the adaptive feedback experiences (used in 7 studies) offer incremental support based on learners' performance. In this case, learners' agency is supported but some considerations must be made depending on the inquiry activity. In (Chu, Hwang, Tsai, & Tseng, 2010) learners were guided to do field observations in conditional steps. Based on their performance they received different hints to continue the exploration. During the activity, the observation and the hints received were recorded so learners can monitor their steps. In this example, the learners' agency is limited because they received information about strategies to explore the field. However, in (Hung, Hwang, Lin, 2013) they used an automated feedback meant to motivate learners' reflections. In this case, no constraints were found for goal, content or strategy decision on the inquiry activity. In both cases the control over the actions might be influenced the adaptive feedback.

Table 10. Learner's agency dimensions for types of mobile activities providing contextual support

Contextual support	goals	content	actions	strategies	reflection	monitor
Augmented experience	✓	×	✓	✓	✓	×
Immersive experience	✓	✓	✓	✓	✓	✓
Adaptive feedback	✓	✓	×	✓	✓	✓

6. Discussion

The inclusion of mobile technology to support inquiry-based learning processes, has provided ubiquitous opportunities for learners to carry out inquiry processes in a more self-directed way. However, little is known about the degree in which the type of mobile activities in inquiry-based learning, provide real opportunities for learners to exercise their agency. Additionally, although research pointed out the need for tighter guidance and scaffolding in inquiry-based learning and open ended processes (Alfieri et al., 2011; Hmelo-Silver, Duyncan, & Chinn, 2007; Kirschner et al., 2006; Lazonder & Harmsen, 2016), there are not so many practical strategies for practitioners to enact the right balance between learner's agency and scaffolding. Thus, this review provides a strategy to identify the level of agency support for a given type of mobile activity.

In order to deepen our research in the learners' agency (Bandura, 2001; Zimmerman, 1990) –an aspect considered to be essential for inquiry-based learning–, our analysis implemented a three-step process analysis. It started with a state-of-art analysis of the ubiquitous properties in existent mobile frameworks. It revealed that in the context of inquiry-based learning 12 types of mobile activities for inquiry-based learning can be found (see Appendix A). In a second step, to characterize learners' agency 6 dimensions were defined. The dimensions consisted of: 1) learners' control over the goals, 2) learners' control over the content, 3) learners' control over the actions, 4) learners' control over the strategies, 5) learners' opportunities for reflection and 6) learners' opportunities for monitoring their own learning progress. The last step is the actual analysis of the 12 types of mobile activities using the 6 agency dimensions. In Appendix B, while the types of mobile activities that support more learners' agency are placed in the positive side, the ones in the negative side offer less opportunities for learners' agency (or more scaffolding for learners).

Table 11. Learner's agency dimension for each type of mobile activities.

		Learners' agency dimensions					
Types of mobile activities		goals	content	actions	strategies	reflection	monitor
Direct Instruction	*Location guidance*	×	×	×	✓	×	×
	Procedural guidance	×	✓	×	×	✓	✓
	Metacognitive guidance	×	✓	✓	✓	✓	×
Access to content	*Fixed content*	×	×	✓	✓	×	×
	Dynamic content	✓	✓	✓	✓	✓	×
Data collection	*Cooperative data collection*	✓	✓	✓	✓	✓	×
	Collaborative data collection	✓	✓	✓	✓	✓	✓
Peer-to-peer communication	*Social asynchronous*	✓	✓	✓	✓	✓	✓
	Social synchronous	✓	✓	✓	✓	✓	✓
Contextual support	*Augmented experience*	✓	×	✓	✓	✓	×
	Immersive experience	✓	✓	✓	✓	✓	✓
	Adaptive feedback	✓	✓	×	✓	✓	✓

Continuing with the last step of the process, table 11 shows the results of the analysis. A *tick* in the table means that we have found a mobile activity in the studies that enables the control of the learner over a given agency dimension. Conversely, a *cross* means that there has been an evidence that a mobile activity limits or constraints the control of learners over a given agency dimension. This second case must be interpreted with caution, because for some types of mobile activities a *cross* can have a positive interpretation with regards the balancing of support of agency and scaffolding. One example is the agency dimension named *content* in relation to the *fixed content* type of mobile activity. This example shows an obvious limitation of learners' agency while accessing fixed content, because the learner has no control over the content used for the inquiry as it is given by the teacher through the mobile technology. However, although it limits agency, it is a great opportunity for teachers to provide content scaffolding in order to ensure that learners work with desirable concepts. This interpretation can be generalized for the *goals*, *actions* and *strategies* dimensions too, because in case that the agency is limited or constrained it provides opportunities for guiding learners on their learning. For example, with mobile activities that support *metacognitive guidance* learners will have certain degree of freedom, but usually the mandatory reflection moments guide or lead learners to specific learning goals. Similarly, the mobile activities that support *augmented experiences* are suitable for learners to explore the environment, making sure that they stumble upon some desirable concepts needed for their inquiry (often placed in a location or triggered to the learner at a given time). Another example, that shows how the analytical framework can be used to better combined scaffolding with learners' agency can be seen in the *adaptive feedback*. The learners can have control over the inquiry activity but still will be asked to perform specific actions based on their previous performance. This, again, is another type of guidance through mobile technology.

A different interpretation needs to be done for the *reflection* and *monitoring* agency dimensions. The meaning of the information in table 11 still represents is the types of mobile activities enabling monitoring or reflection. But, unlike the other agency dimensions, a cross in *monitoring* or *reflection* means that there is no technical support to monitor or to reflect about their progress. In this sense, techniques like e.g. Learning Analytics can provide means through their dashboards to enhance the support of theses agency dimensions. The learners can trace and visualize their progress over time (Schwendimann et al., 2016) which allows them to monitor their progress. Such monitoring implies more control for learners over their learning to reflect and also to adapt their behavior based on an informed decision.

The analysis of the learners' agency support through mobile activities can have implications for educational practitioners. Through the analytical framework, they have more means to strategically design their mobile activities based on the agency support. It is possible to aim at specific dimensions of agency and to provide guidance for other dimensions in which learners have a deficit on. For example, learners with problems to focus on their learning goals should be supported with mobile activities that provide guidance on pursuing learning goals like e.g. *direct instruction* or *fixed access to content*. That is to say, those learners should not use mobile activities in which they have control over their learning goals like e.g. *data collection* or mobile activities that offer *contextual support*. With this in mind, it is up to the teacher to use the analytical framework and design activities that, first provide direct guidance and then later gradually design new ones e.g. based on contextual support of peer-to-peer interaction, in which they have a higher degree of agency.

Taken together, the findings presented in this study, the analytical framework and the examples of how to use it, contribute to overcome the criticism about discovery learning processes or methodologies that enable more learners' agency (Kirschner et al., 2006; Mayer, 2004). Because it presents practical instruments for practitioners to optimally balance learners' scaffolding and agency through mobile technology, without jeopardizing the natural capacity of learners' to be autonomous on their learning (E. Tan, So, & Zhang, 2012). These findings also align with the claims made in a recent meta-analysis on inquiry-based learning, that pointed out the relevance of providing instruction and support during the inquiry-based process (Alfieri et al., 2011; Lazonder & Harmsen, 2016).

Finally, this analysis provides two main outcomes in relation to the state-of-art of mobile inquiry-based learning and its implications supporting learners' agency. First, it provides a summary of the most typical types of mobile activities in inquiry-based learning, as well as the technological affordances used to enact them. The second outcomes of this review is the analytical framework that can be used by practitioners to design more balanced mobile activities in inquiry-based learning. This instrument allows them to design mobile inquiry activities that gradually foster the different dimensions of learners' agency. Moreover, it helps to raise awareness about the potential of mobile technology to enable learners' agency. In line with Vogel's criticism (Vogel et al., 2009), the inclusion of mobile technology on inquiry-based learning is not enough to have autonomous and seamless learning processes. It requires agentic learners that make a step further and take control over their learning. To this end, our analytical framework and the analysis done contributed to identify and promote the inclusion and usage of suitable types of mobile activities that support learners' agency.

7. Conclusions

This review aims at examining to what extend the use of mobile technology for inquiry-based learning supports and limits learners' agency. To this end, 62 studies about mobile inquiry-based learning have been analyzed through the types of mobile activities included in their designs. In a second step of our evaluation, the analytical framework extracted from the definitions of agency in the literature revealed 6 dimensions for learners' agency (control over goals, over content, over actions, over strategies, and options for reflection and monitoring). These were used to evaluate 12 types of mobile activities derived from the direct instruction, access to content, data collection, peer-to-peer interaction and contextual support type of mobile activities. As a result, the review provides an indication of what aspects of the learners' agency can be exercise with the different types of mobile activities (see Appendix B). Despite the exploratory nature, the contribution of this review is twofold: first it contributes a systematic review of the types of mobile activities used in inquiry-based learning (see Appendix A). Second, it provides a preliminary analytical framework (see section 3) that can raise awareness about the role of mobile technology to support learners' agency and scaffolding.

There are several limitations associated to this study. The majority of the studies found were case studies because of the lack of a larger body of experimental research studies. This has made it difficult to draw conclusion about the effectiveness of these types of mobile activities supporting learners' agency. Another limitation comes from number of articles analyzed, which was not exhaustive. For example in our search we excluded the term discovery learning which was merged with inquiry-based learning in 1998 (De Jong & Joolingen, 1998). Including this term in our research might be resulted in a more comprehensive list of analyzed work. Also the reliability of the analytical framework has not been discussed thoroughly and it suggests a follow up investigation to validate the agency dimensions. Additionally, the age range of the students and the relation between learners' agency and scaffolding (without mobile technology) have not been taken into consideration. Nevertheless, these limitations do not alter the main outcome of the study.

Recent meta-analysis on inquiry-based learning (Alfieri et al., 2011; Lazonder & Harmsen, 2016) have pointed out the importance of instruction and support in the inquiry process. The use of mobile devices for inquiry-based learning is able to foster different types of mobile activities combining a mix of instruction and agency for the learners. This review has distilled suggestions for such combination to be successful. For example, the use of metacognitive guidance, as part of the direct instruction mobile activities, provides a good balance between learners' agency and learners' scaffolding. The dynamic access to content, as part of the type of mobile activities to access content, offers some chances for learners' agency, but also helps to improve learners' digital literacy skills. The type of mobile activities for contextual support provide some opportunities for learners to control aspects of their learning. Nevertheless, there are some types of contextual support that can undermine the learners' control over the content and their actions. The last two types of mobile activities, data collection and peer-to-peer interaction, allow learners to have most of the control over their inquiry process. However, those types of mobile activities in order to be successful require a good combination and balance with the other three types of mobile activities: direct instruction, access to content and contextual support.

Taken together, this review provides a preliminary work to better understand the influence of mobile technology on learners' agency for inquiry-based learning. Several reflections emerge from this study advocating caution while finding the optimal support and balance between learners' agency and scaffolding. First, we advise for more teachers' and learners' reflection about the use and appropriation (Pachler, Cook, & Bachmair, 2010) of mobile technology for learning. Such reflection can improve the skills of self-identifying learning strategies and consequently lead to more genuine agentic learning (Song et al., 2012). Second, more experimental research is needed to find the optimal proxy for learners' agency, not only for mobile inquiry-based learning but also in broader contexts.

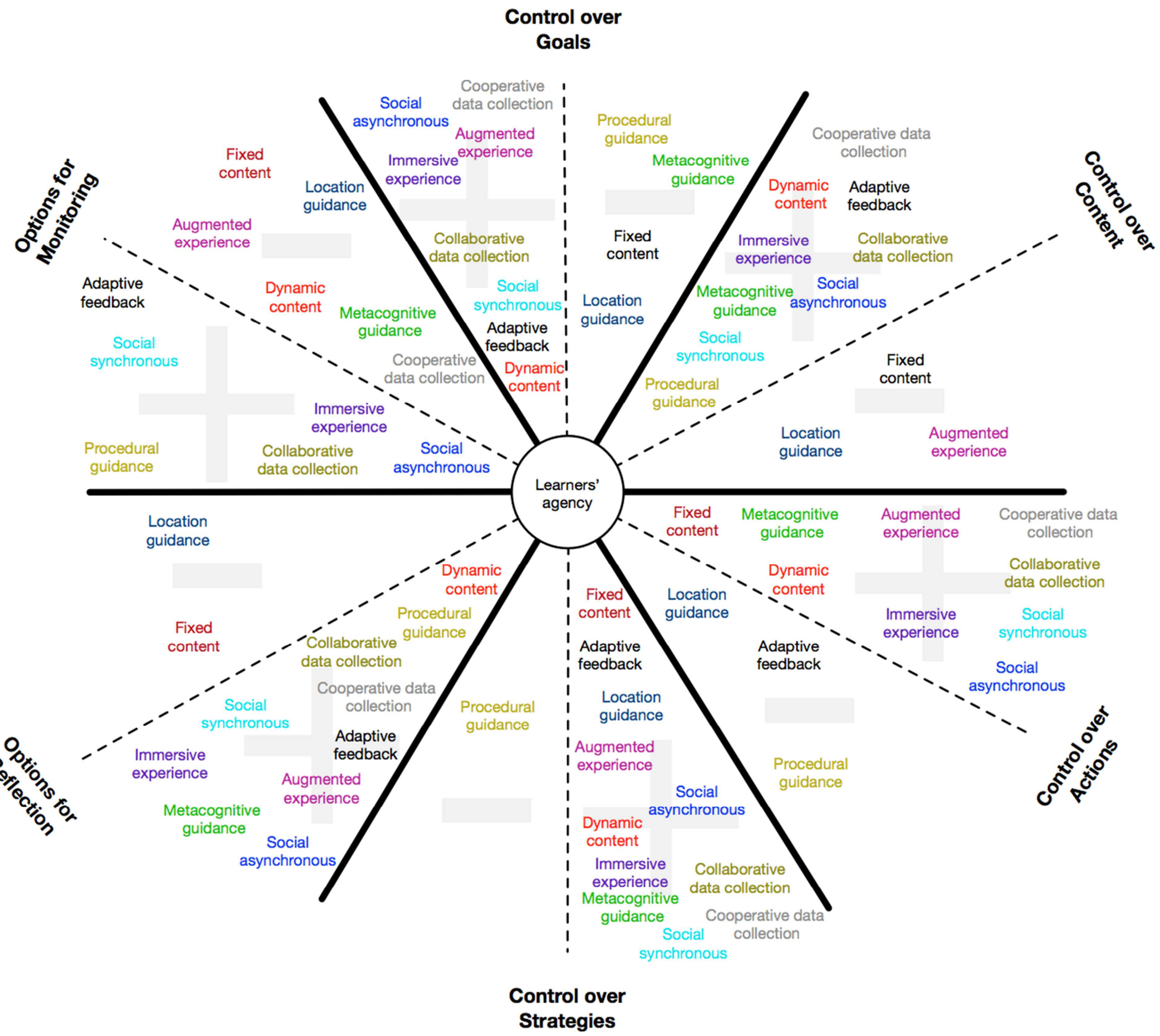
Finally, in the fast-growing field of wearable applications and sensor devices for real world data collection and activity tracking, we foresee further possibilities for intelligent support for inquiry-based processes. This will call for new analysis of learners' agency, in which the study of learners' agency done in this review could be taken as a basis for further improvements.

Appendix A. Complete list of reviewed studies

	Instruction driven			*Content driven*		*Data collection*		*Peer-to-peer interaction*		*Context*		
	Location	*Procedure*	*Metacognitive*	*Fixed*	*Dynamic*	*Cooperative*	*Collaborative*	*Synchronous*	*Asynchronous*	*Augmented*	*Immersive*	*Adaptive*
(Ahmed & Parsons, 2013)			✓	✓		✓						
(Anastopoulou et al., 2012)		✓				✓			✓			
(Aristeidou et al., 2015)					✓	✓			✓			
(Bannan et al., 2010)					✓	✓						
(Boticki et al., 2015)	✓					✓			✓	✓		
(Buckner & Kim, 2013)					✓	✓						
(Chang et al., 2012)						✓						
(Chen & Lin, 2016)	✓			✓		✓					✓	
(Chiang et al., 2014a)	✓				✓	✓	✓	✓	✓	✓	✓	
(Chiang et al., 2014b)	✓				✓	✓	✓	✓	✓	✓	✓	
(Chu, Hwang, Tsai, et al., 2010)	✓	✓		✓		✓						✓
(Chu, Hwang, & Tsai, 2010)	✓			✓		✓						✓
(Chung et al., 2010)					✓	✓						
(Dunleavy et al., 2009)	✓			✓		✓				✓	✓	
(Eliasson et al., 2013)	✓			✓		✓						
(Hsiao et al., 2016)		✓									✓	
(Huang et al., 2010)		✓		✓	✓	✓				✓		
(Hung et al., 2014)	✓			✓	✓	✓						
(Hung et al., 2012)		✓		✓	✓	✓						✓
(Hung et al., 2013)		✓		✓		✓						✓
(Hwang, Chu, et al., 2011)	✓			✓		✓				✓		
(Hwang, Tsai, et al., 2012)	✓	✓		✓								✓
(Hwang et al., 2011)	✓				✓	✓						✓
(Hwang et al., 2013)	✓			✓		✓					✓	
(Jones et al., 2013)	✓			✓		✓			✓			
(Jong & Tsai, 2016)	✓	✓		✓		✓		✓		✓		
(Kamarainen et al., 2013)	✓		✓	✓		✓				✓	✓	✓
(Kerawalla et al., 2013)		✓				✓						
(Kuhn et al., 2011)	✓					✓						
(Lai et al., 2010)	✓				✓				✓			
(Laru et al., 2012)								✓		✓		
(Liljeström et al., 2013)						✓			✓			
(Liu et al., 2009)		✓			✓							
(Looi et al., 2014)			✓		✓	✓	✓					
(Looi et al., 2011)				✓	✓	✓						
(Lui et al., 2014)		✓				✓					✓	
(Maldonado & Pea, 2010)	✓					✓						
(Marty et al., 2013)	✓				✓	✓			✓			
(Nouri et al, 2013)	✓			✓		✓						
(Parr et al., 2004)			✓	✓		✓						
(Razikin et al., 2009)	✓					✓						
(Roger & Price, 2008)				✓		✓	✓	✓				
(Schaal et al., 2012)	✓			✓	✓	✓				✓		
(Sha et al., 2012)					✓	✓						
(Sharples et al., 2015)		✓				✓	✓					
(Shelley et al., 2015)						✓						
(Shih, 2010)	✓				✓	✓			✓			
(Song & Kong, 2014)				✓	✓	✓	✓	✓	✓			
(Song et al., 2012)		✓			✓	✓						
(Song, 2014)					✓	✓	✓	✓	✓			
(Song, 2016)		✓			✓	✓		✓	✓			
(Suarez et al., 2014)		✓				✓						
(Suarez et al., 2016)		✓				✓		✓				
(Sun et al., 2015)						✓	✓					
(Tan et al., 2007)				✓	✓	✓		✓				
(Ternier et al., 2012)	✓			✓		✓				✓	✓	
(Vavoula et al., 2009)	✓					✓						
(Vogel et al., 2014)						✓						
(Wong, 2013) b	✓				✓	✓			✓	✓		
(Wong, 2013) a					✓	✓			✓			
(Yang & Lin, 2010)		✓		✓		✓						
(Yarnall et al., 2006)						✓						
Total per category	**27 / 62**	**17 / 62**	**4 / 62**	**25 / 62**	**25 / 62**	**57 / 62**	**8 / 62**	**10 / 62**	**15 / 62**	**12 / 62**	**9 / 62**	**7 / 62**

	43%	26%	6%	40%	40%	91%	12%	16%	24%	19%	14%	11%
Total per interaction pattern	44/62 (70%)			43/62 (69%)		57/62 (91%)		20/62 (32%)		22/62 (35%)		

Appendix B. The 12 types of mobile activities analyzed through each of the 6 agency dimensions



References

Ahmed, S., & Parsons, D. (2013). Abductive science inquiry using mobile devices in the classroom. *Computers & Education*, *63*, 62–72. http://doi.org/10.1016/j.compedu.2012.11.017

Akyol, Z., & Garrison, D. R. (2011). Assessing metacognition in an online community of inquiry. *The Internet and Higher Education*, *14*(3), 183–190.

Alfieri, L., Brooks, P. J., Aldrich, N. J., & Tenenbaum, H. R. (2011). Does discovery-based instruction enhance learning?

Anastopoulou, S., Sharples, M., Ainsworth, S., Crook, C., O'Malley, C., & Wright, M. (2012). Creating Personal Meaning through Technology-Supported Science Inquiry Learning across Formal and Informal Settings. *International Journal of Science Education*, *34*(2), 251–273. http://doi.org/10.1080/09500693.2011.569958

Aristeidou, M., Scanlon, E., & Sharples, M. (2015). Weather-it Missions: A Social Network Analysis Perspective of an Online Citizen Inquiry Community (pp. 3–16). http://doi.org/10.1007/978-3-319-24258-3_1

Bandura, A. (2001). Social cognitive theory: An agentic perspective. *Annual Review of Psychology*, *52*(1), 1–26.

Bannan, B., Peters, E., & Martinez, P. (2010). Mobile, Inquiry-Based Learning and Geological Observation. *International Journal of Mobile and Blended Learning*, *2*(3), 13–29. http://doi.org/10.4018/jmbl.2010070102

Benson, P. (2007). Autonomy in language teaching and learning. *Language Teaching*, *40*(1), 21–40.

Bogdan, R. C., & Biklen, S. K. (1998). Foundations of qualitative research in education. *Qualitative Research in Education: An Introduction to Theory and Methods*, 1–48.

Boticki, I., Baksa, J., Seow, P., & Looi, C.-K. (2015). Usage of a mobile social learning platform with virtual badges in a primary school. *Computers & Education*, *86*, 120–136. http://doi.org/10.1016/j.compedu.2015.02.015

Brown, A., & Campione, J. (1994). *Guided discovery in a community of learners.* Retrieved from http://doi.apa.org/psycinfo/1994-98346-008

Bruner, J. S., & Sherwood, V. (1976). Peekaboo and the learning of rule structures. *Play: Its Role in Development and Evolution*, 277–285.

Buckner, E., & Kim, P. (2013). Integrating technology and pedagogy for inquiry-based learning: The Stanford Mobile Inquiry-based Learning Environment (SMILE). *PROSPECTS*, *44*(1), 99–118. http://doi.org/10.1007/s11125-013-9269-7

Chang, C.-H., Chatterjea, K., Goh, D. H.-L., Theng, Y. L., Lim, E.-P., Sun, A., … Nguyen, Q. M. (2012). Lessons from learner experiences in a field-based inquiry in geography using mobile devices. *International Research in Geographical and Environmental Education*, *21*(1), 41–58. http://doi.org/10.1080/10382046.2012.639155

Chen, C.-C., & Lin, P.-H. (2016). Development and evaluation of a context-aware ubiquitous learning environment for astronomy education. *Interactive Learning Environments*, *24*(3), 644–661. http://doi.org/10.1080/10494820.2014.915417

Chen, W., Tan, N. Y. L., Looi, C.-K., Zhang, B., & Seow, P. S. K. (2008). Handheld computers as cognitive tools: Technology-enhanced environmental learning. *Research and Practice in Technology Enhanced Learning*, *3*(3), 231–252.

Chiang, T. H. C., Yang, S. J. H., & Hwang, G.-J. (2014a). An Augmented Reality-based Mobile Learning System to Improve Students' Learning Achievements and Motivations in Natural Science Inquiry Activities. *Educational Technology & Society*, *17*(4), 352–365. Retrieved from

http://www.jstor.org/stable/jeductechsoci.17.4.352
Chiang, T. H. C., Yang, S. J. H., & Hwang, G.-J. (2014b). Students' online interactive patterns in augmented reality-based inquiry activities. *Computers & Education, 78*, 97–108. http://doi.org/10.1016/j.compedu.2014.05.006

Chu, H.-C., Hwang, G.-J., & Tsai, C.-C. (2010). A knowledge engineering approach to developing mindtools for context-aware ubiquitous learning. *Computers & Education*, *54*(1), 289–297. http://doi.org/10.1016/j.compedu.2009.08.023

Chu, H.-C., Hwang, G.-J., Tsai, C.-C., & Tseng, J. C. R. (2010a). A two-tier test approach to developing location-aware mobile learning systems for natural science courses. *Computers & Education*, *55*(4), 1618–1627. http://doi.org/10.1016/j.compedu.2010.07.004

Chu, H.-C., Hwang, G.-J., Tsai, C.-C., & Tseng, J. C. R. (2010b). A two-tier test approach to developing location-aware mobile learning systems for natural science courses. *Computers & Education*, *55*(4), 1618–1627. http://doi.org/10.1016/j.compedu.2010.07.004

Chung, C.-W., Kuo, W.-H., & Liu, C.-C. (2010). Facilitating group learning in science laboratory courses using handheld devices, 182–189. Retrieved from http://dl.acm.org/citation.cfm?id=1854360.1854384

Donovan, M., Bransford, J. D., & Pellegrino, J. (1999). *Ho*. Retrieved from http://files.eric.ed.gov/fulltext/ED440122.pdf

Drexler, W. (2010). The networked student model for construction of personal learning environments: Balancing teacher control and student autonomy. *Australasian Journal of Educational Technology*. Retrieved from http://late-dpedago.urv.cat/site_media/papers/The_networked_student_model_for_construction_of_personal_learning_environments.pdf

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and Limitations of Immersive Participatory Augmented Reality Simulations for Teaching and Learning. *Journal of Science Education and Technology*, *18*(1), 7–22. http://doi.org/10.1007/s10956-008-9119-1

Eliasson, J., Knutsson, O., Ramberg, R., & Cerratto-Pargman, T. (2013). Using Smartphones and QR Codes for Supporting Students in Exploring Tree Species (pp. 436–441). http://doi.org/10.1007/978-3-642-40814-4_35

Fahraeus, E. R. (2004). Distance education students moving towards collaborative learning-A field study of Australian distance education students and systems. *JOURNAL OF EDUCATIONAL TECHNOLOGYAND SOCIETY*, *7*, 129–140.

Fay, B. (1996). *Contemporary philosophy of social science: A multicultural approach* (Vol. 1). Cambridge Univ Press.

Furtak, E. M., Seidel, T., Iverson, H., & Briggs, D. C. (2012). Experimental and Quasi-Experimental Studies of Inquiry-Based Science Teaching: A Meta-Analysis. *Review of Educational Research*, *82*(3), 300–329. http://doi.org/10.3102/0034654312457206

Garrison, D. R., Anderson, T., & Archer, W. (1999). Critical Inquiry in a Text-Based Environment: Computer Conferencing in Higher Education. *The Internet and Higher Education*, *2*(2–3), 87–105. http://doi.org/10.1016/S1096-7516(00)00016-6

Hmelo-Silver, C. E., Duyncan, R. G., & Chinn, C. A. (2007). Scaffolding and Achievement in Problem-Based and Inquiry Learning: A Response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, *42*(2), 99–107. http://doi.org/10.1080/00461520701263368

Holec, H. (1979). *Autonomy and foreign language learning.* ERIC.

Holec, H. A. (1981). Foreign Language Learning. Oxford: Pergamon Press.

Hsiao, H.-S., Chang, C.-S., Lin, C.-Y., & Wang, Y.-Z. (2016). Weather observers: a manipulative augmented reality system for weather simulations at home, in the classroom, and at a museum. *Interactive Learning Environments*, *24*(1), 205–223. http://doi.org/10.1080/10494820.2013.834829

Huang, Y.-M., Lin, Y.-T., & Cheng, S.-C. (2010). Effectiveness of a Mobile Plant Learning System in a science curriculum in Taiwanese elementary education. *Computers & Education*, *54*(1), 47–58. http://doi.org/10.1016/j.compedu.2009.07.006

Huberman, M., & Miles, M. B. (2002). *The qualitative researcher's companion*. Sage.

Hung, C. M., Hwang, G. J., & Wang, S. Y. (2014). Effects of an integrated mind-mapping and problem-posing approach on students' in-field mobile learning performance in a natural science course. *International Journal of Mobile Learning and Organisation*, *8*(3/4), 187. http://doi.org/10.1504/IJMLO.2014.067019

Hung, P., Hwang, G.-J., Su, I., & Lin, H. (2012). A concept-map integrated dynamic assessment system for improving ecology observation competences in mobile learning activities. *TOJET: The Turkish Online Journal of Educational Technology*, *11*(1).

Hung, P., Hwang, G., Lin, Y., Wu, T., & Su, I. (2013). Seamless Connection between Learning and Assessment-Applying Progressive Learning Tasks in Mobile Ecology Inquiry. *Educational Technology & Society*, *16*(1), 194–205. Retrieved from http://www.ifets.info/download_pdf.php?j_id=58&a_id=1327

Hunter, J., & Cooke, D. (2007). Through autonomy to agency: Giving power to language learners.

Hwang, G.-J., Chu, H.-C., Lin, Y.-S., & Tsai, C.-C. (2011). A knowledge acquisition approach to developing Mindtools for organizing and sharing differentiating knowledge in a ubiquitous learning environment. *Computers & Education*, *57*(1), 1368–1377. http://doi.org/10.1016/j.compedu.2010.12.013

Hwang, G.-J., Tsai, C., Chu, H.-C., Kinshuk, & Chen, C.-Y. (2012). A context-aware ubiquitous learning approach to conducting scientific inquiry activities in a science park. *Australasian Journal of Educational Technology*, *28*(5), 931–947.

Hwang, G.-J., Wu, P.-H., & Ke, H.-R. (2011). An interactive concept map approach to supporting mobile learning activities for natural science courses. *Computers & Education*, *57*(4), 2272–2280. http://doi.org/10.1016/j.compedu.2011.06.011

Hwang, G. J., Wu, P. H., Zhuang, Y. Y., & Huang, Y. M. (2013). Effects of the inquiry-based mobile learning model on the cognitive load and learning achievement of students. *Interactive Learning Environments*, *21*(4), 338–354. http://doi.org/10.1080/10494820.2011.575789

Jones, A. C., Scanlon, E., & Clough, G. (2013a). Mobile learning: Two case studies of supporting inquiry learning in informal and semiformal settings. *Computers & Education*, *61*, 21–32. http://doi.org/10.1016/j.compedu.2012.08.008

Jones, A. C., Scanlon, E., & Clough, G. (2013b). Mobile learning: Two case studies of supporting inquiry learning in informal and semiformal settings. *Computers & Education*, *61*, 21–32. http://doi.org/10.1016/j.compedu.2012.08.008

Jong, M. S., & Tsai, C.-C. (2016). Understanding the concerns of teachers about leveraging mobile technology to facilitate outdoor social inquiry learning: the EduVenture experience. *Interactive Learning Environments*, *24*(2), 328–344. http://doi.org/10.1080/10494820.2015.1113710

Jong, T. De, & Joolingen, W. Van. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research*. Retrieved from http://rer.sagepub.com/content/68/2/179.short

Jong, T. De, Specht, M., & Koper, R. (2008). A reference model for mobile social software for learning. *International Journal of Continuing Engineering Education and Life-Long Learning*, *18*(1), 118. http://doi.org/10.1504/IJCEELL.2008.016079

Kamarainen, A. M., Metcalf, S., Grotzer, T., Browne, A., Mazzuca, D., Tutwiler, M. S., & Dede, C. (2013). EcoMOBILE: Integrating augmented reality and probeware with environmental education field trips. *Computers & Education*, *68*, 545–556. http://doi.org/10.1016/j.compedu.2013.02.018

King, A. (2007). Scripting collaborative learning processes: A cognitive perspective. In *Cripting Computer-Supported Collaborative Learning* (pp. 13–37). Springer. http://doi.org/http://dx.doi.org/10.1007/978-0-387-36949-5_2

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching. *Educational Psychologist*, *41*(2), 75–86. http://doi.org/10.1207/s15326985ep4102_1

Klahr, D., & Nigam, M. (2004). The equivalence of learning paths in early science instruction effects of direct instruction and discovery learning. *Psychological Science*. Retrieved from http://pss.sagepub.com/content/15/10/661.short

Koole, M. (2009). A model for framing mobile learning. *Mobile Learning: Transforming the Delivery of …*. Retrieved from https://books.google.nl/books?hl=en&lr=&id=Itp60WteuJsC&oi=fnd&pg=PA25&dq=related:9OH5jM7HSGQJ:scholar.google.com/&ots=5YIML8HTkc&sig=FJiOSuZHPn9itWh9rL4VWm06ES8

Kukulska-Hulme, A. (2009). Will mobile learning change language learning? *ReCALL*, *21*(2), 157. http://doi.org/10.1017/S0958344009000202

Lai, A.-F., Wu, C.-H., Chou, K.-C., & Lai, H.-Y. (2010). Integrate Handheld Device and RFID to Support Context Awareness Environment for Outdoor Inquiry Learning Activity. In *2010 6th IEEE International Conference on Wireless, Mobile, and Ubiquitous Technologies in Education* (pp. 132–136). IEEE. http://doi.org/10.1109/WMUTE.2010.30

Land, S. M., Zimmerman, H. T., Murray, O. T., Hooper, S., Yeh, K. C., & Sharma, P. (2011). Mobile computing: Perspectives on design, learning, and development. 2011 AECT International Convention. *Jacksonville, FL*.

Lantolf, J. P., & Pavlenko, A. (2001). econd (L) anguage (A) ctivity theory: Understanding second language learners as people. *Learner Contributions to Language Learning: New Directions in Research*, 141–158.

Laru, J., Järvelä, S., & Clariana, R. B. (2012). Supporting collaborative inquiry during a biology field trip with mobile peer-to-peer tools for learning: a case study with K-12 learners. *Interactive Learning Environments*, *20*(2), 103–117. http://doi.org/10.1080/10494821003771350

Lazonder, A. W., & Harmsen, R. (2016). Meta-Analysis of Inquiry-Based Learning Effects of Guidance. *Review of Educational Research*, 34654315627366.

Liljeström, A., Enkenberg, J., & Pöllänen, S. (2013). Making learning whole: an instructional approach for mediating the practices of authentic science inquiries. *Cultural Studies of Science Education*, *8*(1), 51–86. http://doi.org/10.1007/s11422-012-9416-0

Little, D. (2007). Language learner autonomy: Some fundamental considerations revisited. *Innovation in Language Learning and Teaching*, *1*(1), 14–29. http://doi.org/10.2167/illt040.0

Liu, T.-Y. (2009). A context-aware ubiquitous learning environment for language listening and speaking. *Journal of Computer Assisted Learning*, *25*(6), 515–527. http://doi.org/10.1111/j.1365-2729.2009.00329.x

Looi, C.-K., Sun, D., Wu, L., Seow, P., Chia, G., Wong, L.-H., … Norris, C. (2014). Implementing mobile learning curricula in a grade level: Empirical study of learning effectiveness at scale. *Computers & Education*, *77*, 101–115. http://doi.org/10.1016/j.compedu.2014.04.011

Luckin, R. (2010). *Re-designing Learning Contexts: Technology-rich, Learner-centred Ecologies*. Taylor

& Francis. Retrieved from http://books.google.com/books?id=I-ZZngEACAAJ&pgis=1

Lui, M., Kuhn, A. C., Acosta, A., Quintana, C., & Slotta, J. D. (2014). Supporting learners in collecting and exploring data from immersive simulations in collective inquiry. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14* (pp. 2103–2112). New York, New York, USA: ACM Press. http://doi.org/10.1145/2556288.2557162

Lumpe, A., & Oliver, J. (1991). Dimensions of hands-on science. *The American Biology Teacher*. Retrieved from http://www.jstor.org/stable/4449322

Maaß, K., & Artigue, M. (2013). Implementation of inquiry-based learning in day-to-day teaching: a synthesis. *ZDM*, *45*(6), 779–795. http://doi.org/10.1007/s11858-013-0528-0

Marty, P. F., Alemanne, N. D., Mendenhall, A., Maurya, M., Southerland, S. A., Sampson, V., … Schellinger, J. (2013). Scientific inquiry, digital literacy, and mobile computing in informal learning environments. *Learning, Media and Technology*, *38*(4), 407–428. http://doi.org/10.1080/17439884.2013.783596

Mayer, R. (2004). Should there be a three-strikes rule against pure discovery learning? *American Psychologist*. Retrieved from http://psycnet.apa.org/journals/amp/59/1/14/

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Annals of Internal Medicine*, *151*(4), 264–269. Retrieved from http://annals.org/aim/article/744664/preferred-reporting-items-systematic-reviews-meta-analyses-prisma-statement

Mulholland, P., Anastopoulou, S., Collins, T., Feisst, M., Gaved, M., Kerawalla, L., … Wright, M. (2012). nQuire: Technological Support for Personal Inquiry Learning. *IEEE Transactions on Learning Technologies*, *5*(2), 157–169. http://doi.org/10.1109/TLT.2011.32

Munby, H. (1989). Reflection-in-action and Reflextion-on-action. *Issues in Education*, *9*, 31–42.

Nathan, M., & Robinson, C. (2001). Considerations of learning and learning research: Revisiting the" media effects" debate. *Journal of Interactive Learning Research*, *12*(1), 69.

Nouri, J., Cerrato-pargman, T., & Zetali, K. (2013). Mobile Inquiry-Based Learning A Study of Collaborative Scaffolding and Performance, 464–473.

Nouri, J., Cerratto-Pargman, T., Rossitto, C., & Ramber, R. (2014). Learning with or without mobile devices? A comparison of traditional schoolfield trips and inquiry based mobile learning activities. Retrieved August 21, 2014, from http://www.apsce.net/uploaded/filemanager/ec853a85-ba5f-44b6-824e-a7b2e9bd66c5.pdf

Pachler, N., Cook, J., & Bachmair, B. (2010). Appropriation of Mobile Cultural Resources for Learning. *International Journal of Mobile and Blended Learning*, *2*(1), 1–21. http://doi.org/10.4018/jmbl.2010010101

Pachler, N., Cook, J., & Bachmair, B. (2012). Appropriation of mobile cultural resources for learning. In *Refining current practices in mobile and blended learning: New applications* (pp. 10–30). IGI Global.

Park, Y. (2011, January 19). A pedagogical framework for mobile learning: Categorizing educational applications of mobile technologies into four types. *Review of Research in Open and Distributed Learning*. Retrieved from http://www.irrodl.org/index.php/irrodl/article/view/791/1748

Parr, C., Jones, T., & Songer, N. (2004). Evaluation of a handheld data collection interface for science learning. *Journal of Science Education and …*. Retrieved from http://link.springer.com/article/10.1023/B:JOST.0000031262.22712.e0

Parr, C. S., Jones, T., Songer, N. B., & Arbor, A. (2002). CyberTracker in BioKIDS : Customization of a PDA-based scientific data collection application for inquiry learning BioKIDS : Kids ' Inquiry of Diverse Species Initial Design CyberTracker software, 1–8.

Pedaste, M., Mäeots, M., Siiman, L. A., de Jong, T., van Riesen, S. A. N., Kamp, E. T., … Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, *14*, 47–61. http://doi.org/10.1016/j.edurev.2015.02.003

Pedaste, M., & Sarapuu, T. (2006). Developing an effective support system for inquiry learning in a Web-based environment. *Journal of Computer Assisted Learning*, *22*(1), 47–62.

Piaget, J. (1959). *The language and thought of the child* (Vol. 5). Psychology Press.

Pierce, C. (1955). Philosophical Writings of Pierce, ed. *J. Buchler. New York: Dover Publications. OBJECTIFICATION*, *73*, 5–20.

Puntambekar, S., & Kolodner, J. L. (2005). Toward implementing distributed scaffolding: Helping students learn science from design. *Journal of Research in Science Teaching*, *42*(2), 185–217.

Razikin, K., Goh, D. H.-L., Theng, Y.-L., Nguyen, Q. M., Kim, T. N. Q., Lim, E.-P., … Sun, A. (2009). Sharing Mobile Multimedia Annotations to Support Inquiry-Based Learning Using MobiTOP (pp. 171–182). http://doi.org/10.1007/978-3-642-04875-3_21

Rogers, Y. (2006). Moving on from Weiser's Vision of Calm Computing: Engaging UbiComp Experiences. In *UbiComp 2006: Ubiquitous Computing* (pp. 404–421). Retrieved from http://www.springerlink.com/index/x60w551565354377.pdf

Rogers, Y., & Price, S. (2008). The Role of Mobile Devices in Facilitating Collaborative Inquiry in situ. *Research and Practice in Technology Enhanced …*. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:The+role+of+mobile+devices+in+facilitating+collaborative+inquiry+in+situ#0

Säljö, R. (2010). Digital tools and challenges to institutional traditions of learning: technologies, social memory and the performative nature of learning. *Journal of Computer Assisted Learning*, *26*(1), 53–64.

Sawyer, R. K. (2005). *The Cambridge handbook of the learning sciences*. Cambridge University Press.

Schaal, S., Matt, M., & Grübmeyer, S. (2012). Mobile Learning and Biodiversity–Bridging the Gap between Outdoor and Inquiry Learning in Pre-Service Science Teacher education. *Procedia - Social and Behavioral Sciences*, *46*, 2327–2333. http://doi.org/10.1016/j.sbspro.2012.05.479

Schwendimann, B., Rodriguez-Triana, M., Vozniuk, A., Prieto, L., Boroujeni, M., Holzer, A., … Dillenbourg, P. (2016). Perceiving learning at a glance: A systematic literature review of learning dashboard research. *IEEE Transactions on Learning Technologies*, *Early Acce*(1), 1–1. http://doi.org/10.1109/TLT.2016.2599522

Sha, L., Looi, C.-K., Chen, W., Seow, P., & Wong, L.-H. (2012). Recognizing and measuring self-regulated learning in a mobile learning environment. *Computers in Human Behavior*, *28*(2), 718–728. http://doi.org/10.1016/j.chb.2011.11.019

Sharples, M., Scanlon, E., Ainsworth, S., Anastopoulou, S., Collins, T., Crook, C., … O'Malley, C. (2015). Personal Inquiry: Orchestrating Science Investigations Within and Beyond the Classroom. *Journal of the Learning Sciences*, *24*(2), 308–341. http://doi.org/10.1080/10508406.2014.944642

Sharples, M., Taylor, J., & Vavoula, G. (2005). Towards a Theory of Mobile Learning. *Proceedings of mLearn 2005*, *1*, 1–9. http://doi.org/citeulike-article-id:6652555

Sharples, M., Taylor, J., & Vavoula, G. (2010). A theory of learning for the mobile age. *Medienbildung in Neuen Kulturräumen*. Retrieved from http://link.springer.com/10.1007/978-3-531-92133-4_6

Shelley, T. R., Dasgupta, C., Silva, A., Lyons, L., & Moher, T. (2015). PhotoMAT: A Mobile Tool for Aiding in Student Construction of Research Questions and Data Analysis. *Technology, Knowledge and Learning*, *20*(1), 85–92. http://doi.org/10.1007/s10758-014-9235-3

Shih, J. (2010). An Inquiry-based Mobile Learning Approach to Enhancing Social Science Learning Effectiveness. *Educational Technology & Society*. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=14364522&AN=57310782&h=w9TuGlsGUNXhM1/x1++zCND2r0+VrIMIC23PbDMr3E3jKIVu+/sy+ZrTSz928+M9fgqgzYxaCQqy2uRBSN8xuw==&crl=c

Song, Y. (2014). “Bring Your Own Device (BYOD)” for seamless science inquiry in a primary school. *Computers & Education*, *74*, 50–60. http://doi.org/10.1016/j.compedu.2014.01.005

Song, Y. (2016). “We found the ‘black spots’ on campus on our own”: development of inquiry skills in primary science learning with BYOD (Bring Your Own Device). *Interactive Learning Environments*, *24*(2), 291–305. http://doi.org/10.1080/10494820.2015.1113707

Song, Y., & Kong, S. C. (2014). Going beyond textbooks: a study on seamless science inquiry in an upper primary class. *Educational Media International*, *51*(3), 226–236. http://doi.org/10.1080/09523987.2014.968450

Song, Y., Wong, L.-H., & Looi, C.-K. (2012). Fostering personalized learning in science inquiry supported by mobile technologies. *Educational Technology Research and Development*, *60*(4), 679–701. http://doi.org/10.1007/s11423-012-9245-6

Specht, M., Bedek, M., Duval, E., & Held, P. (2013). WESPOT: Inquiry based learning meets learning analytics. Retrieved from http://bg-openaire.eu/handle/10867/130

Suarez, A., Ternier, S., Kalz, M., & Specht, M. (2015). Supporting Inquiry-based Learning with Google Glass (GPIM). *Interaction Design and Architecture(s) Journal - IxD&A*, *24*, 100–110.

Suárez, Á., Ternier, S., Prinsen, F., & Specht, M. (2016). Nurturing Communities of Inquiry: A Formative Study of the DojoIBL Platform. In K. Verbert, M. Sharples, & T. Klobučar (Eds.), *Adaptive and Adaptable Learning: 11th European Conference on Technology Enhanced Learning, EC-TEL 2016, Lyon, France, September 13-16, 2016, Proceedings* (pp. 292–305). Cham: Springer International Publishing. http://doi.org/10.1007/978-3-319-45153-4_22

Sun, D., Looi, C.-K., Wu, L., & Xie, W. (2015). The Innovative Immersion of Mobile Learning into a Science Curriculum in Singapore: an Exploratory Study. *Research in Science Education*. http://doi.org/10.1007/s11165-015-9471-0

Sung, Y.-T., Chang, K.-E., & Liu, T.-C. (2016). The effects of integrating mobile devices with teaching and learning on students’ learning performance: A meta-analysis and research synthesis. *Computers & Education*, *94*, 252–275. http://doi.org/10.1016/j.compedu.2015.11.008

Tabuenca, B., Kalz, M., Drachsler, H., & Specht, M. (2015, November 3). Time will tell: The role of mobile learning analytics in self-regulated learning. Retrieved from http://dspace.ou.nl/handle/1820/6172

Tan, E., So, H., & Zhang, X. (2012). Teacher agency and student autonomy in inquiry-based mobile learning trail. Retrieved from http://repository.nie.edu.sg/jspui/handle/10497/5501

Tan, T.-H., Liu, T.-Y., & Chang, C.-C. (2007). Development and Evaluation of an RFID-based Ubiquitous Learning Environment for Outdoor Learning. *Interactive Learning Environments*, *15*(3), 253–269. http://doi.org/10.1080/10494820701281431

Ternier, S., Klemke, R., Kalz, M., & Specht, M. (2012). ARLearn: augmented reality meets augmented virtuality. *Journal of Universal Computer Science - Technology for Learning across Physical and Virtual Spaces [Special Issue]*, *18*(15), 2143–2164. http://doi.org/dx.doi.org/10.3217/jucs-018-15-2143

Thüs, H., Chatti, M. A., Yalcin, E., Pallasch, C., Kyryliuk, B., Mageramov, T., & Schroeder, U. (2012). Mobile learning in context. *International Journal of Technology Enhanced Learning*, *4*(5–6), 332–344.

Verpoorten, D. (2012, November 29). Reflection amplifiers in self-regulated learning. Retrieved from http://dspace.ou.nl/handle/1820/4560

Vogel, D., Kennedy, D., & Kwok, R. C.-W. (2009). Does using mobile device applications lead to learning? *Journal of Interactive Learning Research*, *20*(4), 469.
Vygotsky, L. S. (1978). Mind in society: The development of higher mental process. Cambridge, MA: Harvard University Press.
West, M., & Vosloo, S. (2013). UNESCO policy guidelines for mobile learning. *United Nations Educational, Scientific and Cultural Organization*.
Wilde, D., Harris, E., Rogers, Y., & Randell, C. (2003). The Periscope: supporting a computer enhanced field trip for children. *Personal and Ubiquitous Computing*, *7*(3–4), 227–233. http://doi.org/10.1007/s00779-003-0230-2
Wong, L.-H. (2013). Enculturating self-directed learners through a facilitated seamless learning process framework. *Technology, Pedagogy and Education*, *22*(3), 319–338. http://doi.org/10.1080/1475939X.2013.778447
Wong, L. H., Milrad, M., & Specht, M. (2015). *Seamless Learning in the Age of Mobile Connectivity*. (L.-H. Wong, M. Milrad, & M. Specht, Eds.)*Seamless Learning in the Age of Mobile Connectivity*. Singapore: Springer Singapore. http://doi.org/10.1007/978-981-287-113-8
Yang, J. C., & Lin, Y. L. (2010). Development and Evaluation of an Interactive Mobile Learning Environment with Shared Display Groupware. *Journal of Educational Technology & Society*, *13*(1), 195–207.
Yarnall, L., Shechtman, N., & Penuel, W. R. (2006). Using Handheld Computers to Support Improved Classroom Assessment in Science: Results from a Field Trial. *Journal of Science Education and Technology*, *15*(2), 142–158. http://doi.org/10.1007/s10956-006-9008-4
Zimmerman, B. J. (1990). Self-regulated learning and academic achievement: An overview. *Educational Psychologist*, *25*(1), 3–17.
Zimmerman, B. J., & Schunk, D. H. (2001). *Self-regulated learning and academic achievement: Theoretical perspectives*. Routledge.
Zydney, J. M., & Warner, Z. (2016). Mobile apps for science learning: Review of research. *Computers & Education*, *94*, 1–17. http://doi.org/10.1016/j.compedu.2015.11.001

Acknowledgments The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement N° 318499 - weSPOT project.

Highlights

- A review study about 62 articles on mobile inquiry-based learning (IBL)
- 12 types of mobile activities supported with mobile technology
- An analytical framework for learners' agency with 6 dimensions
- Analysis of the 12 types of mobile activities through the 6 agency dimensions
- Strategies to provide a better balance between learners' agency and scaffolding